Early Growth of Four Species Planted at Three Spacings on Vancouver Island

by
S.A.Y. Omule

B.C. Ministry of Forests and Lands
Research Branch
31 Bastion Square
Victoria, B.C.
V8W 3E7

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Canadian Forestry Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
(604) 388-0600

or

B.C. Ministry of Forests
and Lands
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(604) 387-6719

ABSTRACT

Seedling survival and 24- to 26-year growth of coastal Douglas-fir, Sitka spruce, western hemlock, and western redcedar plantations at 2.7 x 2.7-m, 3.7 x 3.7-m, and 4.6 x 4.6-m spacings were studied on the west coast of Vancouver Island, British Columbia. Initial spacing had no significant effect on seedling survival, which was over 80% in all species but western hemlock (56%). The growth of Douglas-fir in relation to initial spacing was generally as expected: average height was virtually the same in all spacings; wider spacings produced larger trees which became merchantable sooner; and volume yield per hectare was lower at the wider spacings. The impact of initial spacing on growth and yield was not found in Sitka spruce, western hemlock, and western redcedar. Salal (*Gautheria shallon* Pursh.) presence, weevil damage (Sitka spruce), browsing (western redcedar), and poor establishment survival (western hemlock) have confounded or delayed the initial spacing effects in these species.

Juvenile growth curves, which can help in validating growth models and evaluating early plantation performance, have been developed for Douglas-fir and western redcedar. The field plots themselves provide a unique visual demonstration of the effects of the current range of operational stocking levels and tree species selection, as well as an opportunity for investigating how salal, other lesser vegetation, and weevil damage affect tree and stand growth.

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INTRODUCTION

Initial spacing of plantations is an important means of shaping future management options and the yield and value of forests, and therefore, the relative growth of a given tree species planted at different initial spacings on a common site is of considerable interest. The B.C. Ministry of Forests and Lands Research Branch Experimental Project (EP) 571 — a species and initial spacing study — provides a unique opportunity to make such comparisons on the west coast of Vancouver Island.

Coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western redcedar (*Thuja plicata* Donn.), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) plantations were established with the following objectives:[1]

1. to study seedling survival and early growth prior to canopy closure and beyond, if stand conditions (e.g., stand density) are still favourable.
2. to determine site changes that may occur under plantations of these species.
3. to describe the economics and growth and yield of initial spacing on different sites.

It was anticipated that over time the information would help in evaluating species selection guidelines, demonstrating target stocking practised in the Vancouver Forest Region, and validating growth models.

This report summarizes the results and conclusions of EP 571 to age 26.[2]

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1 Heatherington, J.C. 1961. Trials of tree species and initial spacing on the west coast of Vancouver Island. Working plan, EP 571. B.C. Ministry of Forests and Lands, Research Branch File, EP 571.

2 A more detailed account of the experiment is presented in a 1986 progress report on EP 571: Initial spacing-species study on the west coast of Vancouver Island, by S.A.Y. Omule. B.C. Ministry of Forests and Lands, Research Branch, Victoria, B.C.

METHODOLOGY

Study Area

The study area is situated at three locations on the west coast of Vancouver Island: Port Renfrew (latitude 48° 33-36' N; longitude 124° 19-21' W; elevation 20-300 m), Franklin River (latitude 48° 50-54' N; longitude 124° 46-54' W; elevation 90-250 m), and Mooyah Bay (latitude 49° 36' N; longitude 126° 24' W; elevation 160 m). The study areas, located within the Windward Submontane Maritime Wetter Coastal Western Hemlock (CWHb1) variant (Klinka *et al.* 1984), initially supported old-growth stands of western hemlock, western redcedar, amabilis fir (*Abies amabilis* (Dougl.) Forbes), and some Douglas-fir and Sitka spruce. The areas were logged between 1958 and 1960, and slashburned to various extents in 1961. The soil moisture and nutrient regimes range from slightly dry and nutrient-poor to very moist and nutrient-very rich.[3] Douglas-fir site indices ranged from 29 to 44 m at 50 years breast-height age, based on Bruce's (1981) site curves.

The climate at all study locations is generally cool and wet. Snow is intermittent from December to February and does not remain long. Summer fog is common.

Study Design and Assessment

The experiment was planted in a randomized complete block, with a partial three-factor factorial arrangement (Table 1). Each treatment combination was replicated twice. A replicate (plot) consists of 81 trees planted in nine rows with nine trees per row. The outer 32 sample trees in each plot buffer the plots from the surrounding plantations or naturally regenerated stands. The plots were planted in April 1962 with 2+0 bareroot stock raised in the Duncan Nursery from the seed sources listed below:

Species	Seedlot	Seed source	
		Location	Elevation (m)
Douglas-fir	490/59	Gold River	213-335
Western redcedar	B2/483/59	Sarita River	180-213
Sitka spruce	486/59	Sarita River	76-107
Western hemlock	B4/MD/56	Great Central Lake	122-180

The weather at the time of planting was exceptionally dry, warm, and sunny, with strong winds.

The plots have been maintained and periodically remeasured (Table 2). Deer browsing of the planted trees, particularly western redcedar, was common. Dead candidate trees were replaced during remeasurement with comparable naturally regenerated trees growing nearby, when they were available. Other coniferous regeneration was cut. Lesser vegetation, predominantly salal (*Gaultheria shallon* Pursh.) was left. A subsample of trees was measured for total height after 1981. Imperial measurements made prior to 1975 were converted to metric before analysis.

Analysis

The analysis tested the hypothesis that initial spacing did not affect seedling survival and the early growth and yield of each species. The economics of initial spacing was not evaluated. Site changes could not be detected because detailed soil and vegetation descriptions had not been done at study establishment.

Seedling survival

Survival after the first and sixth growing seasons was expressed as a percentage of the nominal number planted, and summarized by treatment and cause of mortality. The survival percentages were transformed using the arcsine transformation (Bartlett 1949), and the treatment means from data subsets representing complete factorials (Table 1) were compared using analysis of variance. When the treatment effects were significant ($p = 0.05$), the treatment means were separated by Tukey's test (see, for example, SAS Institute Inc., 1982, p. 172).

[3] Site descriptions were conducted by G. Krumlik, A. Scagel, and K. Falkiner between 1984 and 1986. The sites were not described at study establishment.

TABLE 1. EP 571 study design

Location	Spacing (m)	North aspect				South aspect				Valley bottom							
										High elevation				Low elevation			
		Fd	Ss	Cw	Hw	Fd	Ss	Cw	Hw	Fd	Ss	Cw	Hw	Fd	Ss	Cw	Hw
Port Renfrew	2.7 x 2.7	3	5	4	2	18	36	23	22	-	-	-	-	42	43	41	45
		7	13	6	16	25	38	32	31	-	-	-	-	44	46	48	47
	3.7 x 3.7	1	9	11	10	37	28	26	24	-	-	-	-	-	-	-	-
		8	12	14	15	39	35	34	40	-	-	-	-	-	-	-	-
	4.6 x 4.6	-	-	-	-	20	17	29	19	-	-	-	-	-	-	-	-
		-	-	-	-	27	21	30	33	-	-	-	-	-	-	-	-
Franklin River	2.7 x 2.7	53	50	49	51	126	119	116	117	60	62	61	57	98	99	84	83
		54	56	52	55	127	124	123	121	76	66	71	75	101	102	100	95
	3.7 x 3.7	-	-	-	-	112	111	125	118	63	68	64	67	87	85	90	86
		-	-	-	-	122	115	128	120	79	69	65	80	89	88	91	92
	4.6 x 4.6	-	-	-	-	105	108	109	106	59	58	73	72	94	82	81	96
		-	-	-		107	110	113	114	70	74	78	77	104	97	93	103
Mooyah Bay	2.7 x 2.7	-	-	-	-	139	135	141	132	-	-	-	-	-	-	-	-
		-	-	-	-	144	143	142	137	-	-		-	-			
	3.7 x 3.7	-	-	-		140	130	138	136	-	-	-	-	-			
		-	-	-	-	146	147	145	148	-	-	-	-	-	-	-	-
	4.6 x 4.6	-	-	-		131	133	129	149	-	-	-	-	-	-	-	
		-	-	-	-	152	134	151	150	-	-	-	-	-	-	-	-

NOTES:

1. Additional one plot of mountain hemlock (153), and four of *Abies amabilis* (154-157) are located in Franklin River, planted all at 2.7 x 2.7-m spacing.
2.

Spacing (m)	Plot area (ha)	#	Density (stems/ha)
2.7 x 2.7	0.0368	7	1329
3.7 x 3.7	0.0655	5	748
4.6 x 4.6	0.1024	3	478

3. Plot identification numbers in cells.
4. Fd = Douglas-fir; Ss = Sitka spruce; Cw = western redcedar; Hw = western hemlock

TABLE 2. EP 571 plot assessment and maintenance

Date	Location	Survival	dbh[a]	Height	Maintenance
Spring 1962	PR,FR,MB[b]	/			planted[c]
Spring 1963	PR,FR,MB	/			replanted[d]
Fall 1967	PR,FR	/		/	
Summer 1968	PR,FR				weeded
Summer 1969	PR,FR		/	/	weeded
Summer 1970	PR,FR		/	/	cleaned[e]
Fall 1975	PR		/	/	cleaned pruned[f]
Fall 1977	FR		/	/	cleaned pruned[f]
Fall 1979	PR		/	/	cleaned
Summer 1981	FR,MB		/	/	cleaned
Summer 1983	PR		/	/	cleaned
Spring 1985	FR		/	/	cleaned
Fall 1985	MB		/	/	cleaned

[a] dbh = diameter at breast height (4.5 ft) outside bark.
[b] PR = Port Renfrew; FR = Franklin River; MB = Mooyah Bay.
[c] Planted with 2+0 bareroot stock.
[d] Replanted with reserve 2+0 bareroot stock seedlings left on site after the 1962 planting.
[e] Coniferous regeneration was cut; salal and other lesser vegetation was not cleared.
[f] Trees were pruned to breast height for ease of measurement.

Stand growth and yield

The following entire-stand and crop-tree average and per-hectare values were obtained from individual tree measurements for each plot and period of measurement: average and top height, quadratic mean diameter, basal area, and total and merchantable volume. Top height was calculated as the average height of the 100 largest diameter trees per hectare. Total volume is whole stem, inside bark volume estimated from existing volume tables (B.C. Forest Service 1976; Kovats 1977; G. Godfrey, B.C. Min. For., pers. comm., 1983). Merchantable volume is total volume excluding a 30-cm high stump and a 10-cm diameter inside bark top. Crop-tree summaries were obtained for each plot from measurements of the 250 largest (current) diameter trees per hectare (that is, 4, 6, and 10 trees per plot with dimensions 2.7 x 2.7 m, 3.7 x 3.7 m, and 4.6 x 4.6 m, respectively), which were traced back through the periods of measurement.

Juvenile growth curves — regressions of average and per-hectare values on top height — were developed and compared among the three initial spacings for Douglas-fir and western redcedar. Initial spacing effects were not determined for other species because of the severe weevil attack on Sitka spruce and the extremely low establishment survival of western hemlock. The method of curve fitting suggested by Hui (1984) was used to develop the growth curves, which were in the form of a polynomial function in time or in attained top height. Tests similar to the sequential analysis of variance (Kozak 1970) were used to detect significant differences among the initial spacings for Douglas-fir and western redcedar.[4]

The cumulative frequency distributions of diameter at ages 24 and 25 years in Port Renfrew and Franklin River, respectively, were compared among spacings for Douglas-fir and western redcedar. The last measurement at Mooyah Bay was excluded because graphical displays of the distributions were distinctly different from those of Port Renfrew, due in part to the 2-year difference in remeasurement dates. The total number of trees in each 2-cm diameter class was obtained for all plots (i.e., combining both locations) within each initial spacing level. To determine cumulative percentage frequencies for each initial spacing, diameter class totals from the smallest class to the largest were added, and the cumulative frequency for each class was divided by the total number of trees in the two locations for each initial spacing.

Plotted over diameter classes, the cumulative percentage frequencies described a sigmoid curve having a maximum cumulative percent frequency (100%) as asymptope. A logistic function (Richards 1959) was transformed and fitted by ordinary least squares to the observed cumulative frequencies for each initial spacing, and the resulting curves were visually compared. The transformed logistic function was:

$$\ln [y/(A-y)] = b_o + b_1 X \qquad (1)$$

where

y = diameter cumulative percentage frequency
A = asymptotic cumulative percentage frequency (= 100)
X = diameter class
$b_o;b_1$ = regression coefficients

Mortality was evaluated from age 8 by calculating the number of survivor trees at each measurement period as a percentage of the nominal number planted, and examining the graphical displays of the percentages over total age.

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[4] Further details of the fitting and testing procedures are given in the 1986 progress report on EP 571, by S.A.Y. Omule, B.C. Ministry of Forests and Lands, Research Branch, Victoria, B.C.

RESULTS AND DISCUSSION

Seedling Survival

Initial spacing did not have a significant impact on seedling survival after the first growing season for each species. Western hemlock survival (average 56%) was significantly lower than that of the other species (Sitka spruce 87%; Douglas-fir 86%; western redcedar 91%) (Table 3). Percentage survival after six growing seasons was similar to that after the first growing season (Table 4). In particular, the survival of western hemlock remained low even after fill-in planting. The principal causes of mortality in all species were "unidentified" (probably drought and browsing), although insect (specifically weevil) damage was also important (Table 5).

The poor survival of western hemlock, planted as bareroot stock, has been observed to different degrees elsewhere (e.g., Arnott 1975, p. 191; Reukema and Smith[5]). However, better establishment survival of planted container-grown western hemlock has been reported by Arnott (1975).

There were no significant differences in tree height among the initial spacings at age 8 for each species, although Sitka spruce had the best growth followed by Douglas-fir, western hemlock, and western redcedar (Table 6).

Stand Growth and Yield

Stand growth and yield is described and discussed separately by species. Mortality from inter-tree competition for light and nutrients was generally independent of species and spacings; that is, there had been little differentiation by crown class or suppression of individual trees by their neighbours. The little mortality that did occur is largely attributable to such agents as root rot (in Douglas-fir) and other microsite factors. Other entire-stand and crop-tree values at ages 24 to 26 years are given in Tables 7-10 for the three species. The results of the analyses of the spacing effects are outlined below.

DOUGLAS-FIR

Average height:

Initial spacing did not significantly affect stand average height. The slopes of the regressions of arithmetic average height (AAH) on top height showed that AAH was about 93% of top height at the 2.7-m spacing compared to about 97 and 96% at the 3.7- and 4.6-m spacings, respectively (Figure 1). These slight differences in AAH among initial spacings may be statistical artifacts, or real differences that might persist over time. Douglas-fir was taller than all other species.[6]

The analysis of spacing effects was done almost entirely in terms of the relation of stand values to top height development. The impact of initial spacing on top height was assumed to be negligible, although some differences were evident in top height among spacings (Table 7). For example, top height at age 25 from Franklin River Valley bottom sites was about 1.5 m taller in the 2.7-m spacing than in the 4.6-m spacing; the difference in crop-tree average height was about 2.0 m. Furthermore, it appears that the stand value/top height relationships were slightly affected by site index classes (Figure 2), although the small sample size and the narrow range of site indices represented in the data do not permit a definitive statement.

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[5] Reukema, D.L. and J.H.G. Smith. 1986. Twenty-five year development of Douglas-fir, western hemlock, and western redcedar planted at various spacings on a very good site (University of British Columbia Research Forest). U.S. Dep. Agric., Pac. Northwest For. & Range Exp. Stn., Review draft manuscript.

[6] Omule, S.A.Y. and G.J. Krumlik. 1987. Juvenile height growth of Douglas-fir, Sitka spruce, western hemlock and western redcedar on four sites on the west coast of Vancouver Island. Review manuscript. B.C. Ministry of Forests and Lands, Research Branch, Victoria, B.C.

TABLE 3. Percentage survival after one growing season by species and spacing

Location	Spacing (m)	North aspect				South aspect				Valley bottom							
										High elevation (153 m)				Low elevation (153 m)			
		Fd[a]	Ss	Cw	Hw	Fd	Ss	Cw	Hw	Fd	Ss	Cw	Hw	Fd	Ss	Cw	Hw
Port Renfrew	2.7 x 2.7	87.7	93.8	88.9	81.6	88.9	77.8	80.2	53.1	-	-	-	-	85.2	71.6	92.6	61.2
		88.9	84.0	92.6	53.1	97.5	65.4	87.7	48.1	-	-	-	-	85.2	72.8	92.6	36.7
	3.7 x 3.7	88.9	85.2	87.7	93.9	69.1	95.1	97.5	46.9	-	-	-	-	-	-	-	-
		84.0	93.8	90.1	57.1	74.1	77.8	75.3	40.1	-	-	-	-	-	-	-	-
	4.6 x 4.6	-	-	-	-	86.4	86.4	87.7	55.1	-	-	-	-	-	-	-	-
		-	-	-	-	85.2	87.7	90.1	71.4	-	-	-	-	-	-	-	-
Arith. average		87.4	89.6	89.9	73.5	84.9	82.8	86.7	52.4	-	-	-	-	85.2	72.2	92.6	49.0
Franklin River	2.7 x 2.7	90.1	93.8	96.3	85.7	71.6	86.4	95.1	34.7	92.6	96.3	91.4	79.6	74.1	71.6	90.1	30.6
		85.2	92.6	93.8	73.5	84.0	90.1	91.4	42.0	79.0	79.0	90.1	85.7	71.6	86.4	87.7	51.0
	3.7 x 3.7	-	-	-	-	95.1	60.5	96.3	35.8	86.4	92.6	97.5	46.9	82.7	85.2	75.3	53.1
		-	-	-	-	91.4	88.9	97.5	19.8	91.4	95.1	98.8	42.9	82.7	95.1	82.7	22.4
	4.6 x 4.6	-	-	-	-	87.7	81.5	90.1	25.9	91.4	88.9	98.8	73.5	80.2	93.8	91.4	61.2
		-	-	-	-	95.1	93.8	92.6	13.6	60.5	81.5	95.1	57.1	67.9	96.3	80.2	36.7
Arith. average		87.7	93.2	95.1	80.0	88.5	84.6	94.0	27.9	84.8	89.7	96.0	65.1	76.8	89.3	85.0	42.2
Mooyah Bay	2.7 x 2.7	-	-	-	-	91.4	92.6	86.4	32.7	-	-	-	-	-	-	-	-
		-	-	-	-	92.6	82.7	95.1	79.6	-	-	-	-	-			
	3.7 x 3.7	-	-	-	-	93.8	87.7	87.7	69.4	-	-	-	-	-	-	-	-
		-	-	-	-	82.7	65.4	90.1	42.9	-	-	-	-	-	-	-	-
	4.6 x 4.6	-	-	-	-	84.0	85.2	91.4	53.1	-	-	-	-	-	-	-	-
		-	-	-	-	81.5	91.4	84.0	55.1	-	-	-	-	-	-	-	-
Arith. average		-	-	-	-	88.2	87.4	89.4	55.8	-	-	-	-	-	-	-	-
Grand average		86.0	90.9	92.0	75.7	87.6	85.0	90.2	45.1	84.8	89.7	96.0	65.1	79.0	84.3	87.2	42.9

[a] Fd = Douglas-fir; Ss = Sitka spruce; Cw = western redcedar; Hw = western hemlock.

TABLE 4. Percentage survival after six growing seasons by species and spacing

Location	Spacing (m)	North aspect				South aspect				Valley bottom							
										High elevation (153 m)				Low elevation (153 m)			
		Fd[a]	Ss	Cw	Hw	Fd	Ss	Cw	Hw	Fd	Ss	Cw	Hw	Fd	Ss	Cw	Hw
Port Renfrew	2.7 x 2.7	98.0	100.0	98.0	95.9	91.9	85.7	85.7	63.3	-	-	-	-	95.9	91.9	71.4	42.9
		100.0	95.9	100.0	87.7	93.9	73.4	89.8	73.4	-	-	-	-	93.9	81.6	75.5	69.4
	3.7 x 3.7	100.0	100.0	100.0	89.7	83.6	95.9	97.9	57.1	-	-	-	-	-	-	-	-
		93.9	95.9	100.0	79.5	81.6	91.7	75.4	24.5	-	-	-	-	-	-	-	-
	4.6 x 4.6	-	-	-	-	96.0	86.4	71.5	51.0	-	-	-	-	-	-	-	-
		-	-	-	-	90.0	93.9	81.8	59.2	-	-	-	-	-	-	-	-
Location average		98.0	98.0	99.5	88.2	91.2	84.2	83.7	54.8	-	-	-	-	94.9	86.8	73.5	56.2
Franklin River	2.7 x 2.7	100.0	100.0	100.0	100.0	100.0	98.0	95.9	83.7	91.9	100.0	98.0	69.4	77.6	89.8	89.8	63.3
		95.9	100.0	100.0	93.9	95.9	100.0	100.0	93.9	93.9	95.9	98.0	87.7	87.7	100.0	87.7	57.1
	3.7 x 3.7	-	-	-	-	91.7	93.9	100.0	63.2	100.0	100.0	100.0	73.4	77.5	95.9	91.7	48.9
		-	-	-	-	100.0	95.9	93.9	73.4	87.7	97.9	93.9	48.9	59.1	100.0	91.7	44.9
	4.6 x 4.6	-	-	-	-	77.6	96.0	100.0	51.0	93.9	98.1	91.8	63.4	69.5	96.0	77.6	38.7
		-	-	-		91.8	93.9	93.9	63.4	90.0	100.0	90.0	38.7	79.7	100.0	49.8	36.8
Location average		98.0	100.0	100.0	97.0	92.8	96.3	97.3	71.4	97.0	98.7	95.3	63.7	75.2	97.0	82.9	48.3
Grand average		98.0	99.0	99.8	92.6	92.0	90.3	90.5	63.1	97.0	98.7	95.3	63.7	85.1	91.9	78.2	52.3

[a] Fd = Douglas-fir; Ss = Sitka spruce; Cw = Western redcedar; Hw = western hemlock.

TABLE 5. Percentage seedling mortality by species and cause of mortality

Cause of mortality	First year percentage mortality by species[a]			
	Douglas-fir	Western redcedar	Sitka spruce	Western hemlock
Insect & disease[b]	5.3	0.3	2.8	1.5
Erosion (wash-out)	0.4	1.4	0.1	0.4
Unidentified (probably drought, browsing, frost, etc.)	9.6	8.2	11.3	42.2
Total	15.3	9.9	14.2	44.1

[a] Total number of seedlings inspected = 3078 for each of Douglas-fir, western redcedar and Sitka spruce, and 1862 for western hemlock.
[b] Probably root-collar weevil.

TABLE 6. Tree heights after six growing seasons by species, aspect, and spacing

Location	North aspect				South aspect			
	Cw[a]	Hw	Fd	Ss	Cw	Fd	Hw	Ss
Franklin River				Tree height (cm)				
2.7 x 2.7	147.6 (8.6)[b]	214.7 (10.0)	264.4 (8.0)	238.2 (9.5)	100.4 (3.7)	222.1 (6.5)	183.9 (8.9)	223.5 (8.6)
3.7 x 3.7	-	-	-	-	101.8 (4.4)	261.0 (7.4)	221.9 (11.1)	227.0 (8.8)
4.6 x 4.6	-	-	-	-	116.3 (4.8)	259.2 (9.1)	195.3 (9.9)	230.1 (9.4)
Port Renfrew								
2.7 x 2.7	103.2 (5.3)	187.6 (7.0)	228.7 (9.4)	223.9 (9.7)	61.6 (3.2)	106.4 (5.0)	209.9 (8.2)	263.7 (12.1)
3.7 x 3.7	144.2 (5.4)	187.7 (7.8)	228.9 (7.2)	249.9 (8.5)	86.5 (4.2)	124.1 (6.0)	204.9 (11.9)	191.6 (7.9)
4.6 x 4.6	-	-	-	-	44.9 (3.8)	112.5 (4.7)	218.9 (14.6)	212.3 (5.1)

Location	Valley bottom (high elev.)				Valley bottom (low elev.)			
	Cw	Hw	Fd	Ss	Cw	Fd	Hw	Ss
Franklin River				Tree height (cm)				
2.7 x 2.7	120.7 (6.4)	177.9 (10.9)	249.7 (9.3)	201.7 (8.2)	59.3 (3.0)	175.2 (9.3)	137.3 (7.3)	233.6 (9.3)
3.7 x 3.7	964.2 (4.4)	179.0 (7.3)	217.3 (7.8)	268.2 (7.9)	56.4 (3.2)	138.4 (10.0)	140.7 (6.6)	233.5 (8.3)
4.6 x 4.6	876.4 (4.3)	206.2 (10.8)	208.4 (6.7)	227.3 (7.3)	44.3 (3.6)	172.7 (18.9)	133.8 (7.7)	193.1 (8.2)
Port Renfrew								
2.7 x 2.7	-	-	-	-	67.3 (4.6)	166.1 (13.7)	203.3 (8.3)	172.0 (9.6)
3.7 x 3.7	-	-	-	-	-	-	-	-
4.6 x 4.6	-	-	-	-	-	-	-	-

[a] Cw = western redcedar; Hw = western hemlock; Fd = Douglas-fir; Ss = Sitka spruce
[b] The values in brackets are standard errors.

TABLE 7. Entire-stand and crop-tree 24- to 26-year yields for Douglas-fir

Location, aspect, and initial spacing (m)	Plot average[a] values for standing trees											
	Entire stand							Crop trees[b]				
	Stem count (/ha)	Avg.[c] diam. (cm)	Height Top[d] (m)	Height Avg. (m)	Volume Tot. (m³/ha)	Volume Merch.[e] (m³/ha)	Basal area (m²/ha)	Avg. diam. (cm)	Avg. ht. (m)	Volume Tot. (m³/ha)	Volume Merch. (m³/ha)	Basal area (m²/ha)
Port Renfrew (age 24)[f]												
North aspect												
2.7 x 2.7	1099	19.6	18.4	16.5	229	201	33	25.9	18.2	92	86	13
3.7 x 3.7	664	23.5	16.8	15.9	184	170	29	27.5	16.5	94	89	15
South aspect												
2.7 x 2.7	1167	14.0	13.7	10.4	91	67	18	18.9	12.9	38	33	7
3.7 x 3.7	603	21.4	14.9	14.0	125	113	22	25.1	14.6	70	56	12
4.6 x 4.6	430	18.7	13.2	11.7	62	55	12	20.9	12.8	45	41	9
Valley bottom (low)												
2.7 x 2.7	1072	20.5	17.6	16.1	235	209	35	26.5	17.5	92	87	14
Franklin River (age 25)												
North aspect												
2.7 x 2.7	1032	20.3	20.2	17.1	307	274	42	26.8	19.8	106	100	14
South aspect												
2.7 x 2.7	1248	20.1	18.5	16.8	276	246	40	24.5	18.3	83	78	12
3.7 x 3.7	686	25.2	19.3	18.0	247	231	34	29.3	19.2	122	116	17
4.6 x 4.6	366	30.2	19.2	17.5	180	173	26	32.7	18.5	145	138	21
Valley bottom (high elev.)												
2.7 x 2.7	1235	21.8	18.8	16.7	325	296	46	27.8	18.6	107	102	15
3.7 x 3.7	710	27.2	18.4	17.0	280	264	41	32.1	18.2	137	131	20
4.6 x 4.6	425	27.3	17.2	15.7	160	151	25	30.1	16.8	116	111	18
Valley bottom (low elev.)												
2.7 x 2.7	1044	22.3	19.3	16.6	287	260	41	30.2	19.0	128	122	18
3.7 x 3.7	488	27.3	17.9	15.8	183	172	28	32.1	17.4	131	125	20
4.6 x 4.6	342	31.2	17.9	15.7	164	156	26	34.1	16.8	143	137	22
Mooyah Bay (age 26)												
South aspect												
2.7 x 2.7	1275	17.5	18.8	16.2	214	180	30	22.2	18.3	70	65	9
3.7 x 3.7	725	19.5	19.0	15.7	148	139	22	23.8	18.0	80	74	11
4.6 x 4.6	459	22.9	18.5	16.2	129	119	19	26.2	17.1	91	86	13

[a] The values are averages of the two replicates per treatment combination.
[b] Largest 250 trees per hectare by diameter.
[c] Quadratic mean diameter.
[d] Average height of largest 100 trees per hectare by diameter.
[e] Total volume less a 30-cm high stump and 10-cm diameter inside bark top.
[f] Total age from seed (years).

TABLE 8. Entire-stand and crop-tree 24- to 26-year yields for western redcedar

Location, aspect, and initial spacing (m)	Plot average[a] values for standing trees											
	Entire stand							Crop trees[b]				
	Stem count (/ha)	Avg.[c] diam. (cm)	Height Top[d] (m)	Height Avg. (m)	Volume Tot. (m³/ha)	Volume Merch.[e] (m³/ha)	Basal area (m²/ha)	Avg. diam. (cm)	Avg. ht. (m)	Volume Tot. (m³/ha)	Volume Merch. (m³/ha)	Basal area (m²/ha)
Port Renfrew (age 24)[f]												
North aspect												
2.7 x 2.7	1235	11.2	9.8	7.0	50	16	12	16.5	9.2	23	13	5
3.7 x 3.7	725	17.6	11.2	9.9	86	57	18	22.1	10.9	46	37	10
South aspect												
2.7 x 2.7	1099	9.9	7.9	6.1	34	11	9	13.6	7.5	15	8	4
3.7 x 3.7	412	10.8	7.9	6.8	9	3	3	11.9	7.4	8	3	2
4.6 x 4.6	327	3.1	3.5	2.4	0	0	0	3.6	3.1	0	0	0
Valley bottom (low)												
2.7 x 2.7	936	13.9	10.9	8.7	66	29	14	18.3	10.4	32	21	7
Franklin River (age 25)												
North aspect												
2.7 x 2.7	1262	17.0	12.2	10.0	142	92	29	24.6	11.9	59	50	12
South aspect												
2.7 x 2.7	1234	13.5	10.7	8.6	82	35	18	18.1	10.3	30	20	6
3.7 x 3.7	671	12.7	10.3	7.8	37	15	9	16.5	9.5	24	13	5
4.6 x 4.6	444	17.0	10.8	9.1	45	28	10	19.7	10.2	34	25	7
Valley bottom (high elev.)												
2.7 x 2.7	1262	16.2	10.2	8.5	109	64	26	21.3	9.9	38	30	9
3.7 x 3.7	679	21.8	10.2	8.8	102	82	26	27.2	9.9	58	51	14
4.6 x 4.6	430	21.8	10.2	8.9	64	52	16	24.9	9.8	49	42	12
Valley bottom (low elev.)												
2.7 x 2.7	1072	13.9	9.8	7.3	63	30	16	19.3	9.1	29	21	7
3.7 x 3.7	641	14.1	8.4	6.8	36	19	10	18.4	7.9	24	16	7
4.6 x 4.6	298	14.4	8.6	6.9	18	10	5	15.5	7.6	17	10	5
Mooyah Bay (age 26)												
South aspect												
2.7 x 2.7	1289	12.3	11.3	8.7	75	24	16	16.6	10.5	30	16	6
3.7 x 3.7	694	12.3	11.0	8.3	38	14	8	16.1	10.2	24	13	5
4.6 x 4.6	474	11.3	9.6	7.6	21	6	5	13.9	8.8	17	6	4

[a] The values are averages of the two replicates per treatment combination.
[b] Largest 250 trees per hectare by diameter.
[c] Quadratic mean diameter.
[d] Average height of largest 100 trees per hectare by diameter.
[e] Total volume less a 30-cm high stump and 10-cm diameter inside bark top.
[f] Total age from seed (years).

TABLE 9. Entire-stand 24- to 26-year yields for damaged and undamaged Sitka spruce

Initial spacing (m)	North aspect				South aspect						Valley bottom (high elev.)						Valley bottom (low elev.)					
	2.7		3.7		2.7		3.7		4.6		2.7		3.7		4.6		2.7		3.7		4.6	
	D[a]	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U
Port Renfrew (age: 24 yrs from seed)																						
Stem count (/ha)	434	841	458	267	773	258	229	309	108	327	990	95	-	-	-	-	-	-	-	-	-	-
Average diam. (cm)	19.0	16.1	19.8	18.1	16.9	13.4	9.3	8.6	11.3	9.6	16.7	9.2	-	-	-	-	-	-	-	-	-	-
Average height (m)	11.3	10.8	11.9	11.0	8.9	8.2	4.5	4.4	5.7	4.9	8.8	7.5	-	-	-	-	-	-	-	-	-	-
Franklin River (age: 25 yrs from seed)																						
Stem count (/ha)	597	733	-	-	618	359	313	88	396	44	482	515	298	427	249	225	1180	82	709	29	469	0
Average diam. (cm)	17.7	14.7	-	-	15.8	11.7	17.4	13.2	20.4	21.2	19.6	16.0	23.7	20.9	19.4	17.5	18.4	13.1	22.0	14.9	24.3	-
Average height (m)	11.0	10.2	-	-	8.3	7.0	8.2	6.8	8.3	8.0	9.9	8.3	7.3	10.7	9.3	9.0	9.0	8.5	9.7	8.9	9.1	-
Mooyah Bay (age: 26 yrs from seed)																						
Stem count					165	1004	252	466	186	283												
Average					9.9	8.4	14.1	10.5	10.5	7.5												
Average					6.5	5.5	8.1	7.1	6.5	5.2												

[a] D = damaged; U = undamaged.

TABLE 10. A summary of plot values of western hemlock at 24- to 26-years

Location, aspect, initial spacing (m), and plot	Entire stand and crop-tree values in 1983, 1984 and 1985 for standing trees											
	Entire stand							Crop trees[a]				
	Stem count (/ha)	Avg.[b] diam. (cm)	Height Top[c]	Height Avg. (m)	Volume Tot. (m³/ha)	Volume Merch. (m³/ha)	Basal area (m²/ha)	Avg. diam. (cm)	Avg. ht. (m)	Volume Tot. (m³/ha)	Volume Merch. (m³/ha)	Basal area (m²/ha)
Port Renfrew (age 24)[d]												
North aspect												
2.7 x 2.7 m												
2	1221 (54)[e]	12.1	12.1	8.7 (8.9)[g]	65	44	14	17.1	11.7	30	26	6
16	1221 (100)	18.9	16.7	14.8 (14.8)	233	207	34	24.3	16.2	81	76	11
3.7 x 3.7 m												
10	671 (61)	15.4	14.4	11.2 (11.7)	72	60	12	19.8	13.9	48	44	8
15	717 (122)	20.9	15.5	13.4 (14.0)	156	142	25	26.1	15.1	86	81	13
South aspect												
2.7 x 2.7 m												
22*[f]	1058 (216)	15.1	13.2	10.3 (10.9)	96	77	19	19.9	12.7	43	39	8
31*	1058 (106)	8.5	7.7	5.1 (5.4)	17	7	6	12.3	7.1	10	6	3
3.7 x 3.7 m												
24*	625 (198)	17.3	11.1	9.1 (10.1)	65	57	15	20.8	11.0	40	37	8
Valley bottom (low elev.)												
2.7 x 2.7 m												
47*	1058 (190)	16.1	15.6	10.1 (11.7)	125	108	22	24.0	14.7	74	69	11
Franklin River (age 25)												
North aspect												
2.7 x 2.7 m												
51	1248 (27)	17.1	18.0	13.9 (13.9)	195	166	29	23.5	16.8	81	76	11
55	1275 (54)	15.9	16.0	12.3 (12.6)	158	131	25	23.3	15.3	71	67	11
South aspect												
2.7 x 2.7 m												
117*	1221 (190)	15.9	13.5	10.8 (11.1)	128	106	24	21.7	13.4	54	50	9
121	1166 (54)	13.3	12.5	8.3 (8.4)	69	50	16	18.6	11.1	34	30	7
3.7 x 3.7 m												
118*	686 (244)	16.6	14.0	9.9 (11.7)	84	73	15	22.6	13.2	61	57	10
120*	641 (137)	19.7	15.0	11.7 (12.9)	114	103	20	24.8	14.2	74	70	12
4.6 x 4.6 m												
106*	410 (205)	17.8	13.8	10.8 (12.5)	57	50	10	19.9	12.5	40	37	7
114*	430 (166)	16.0	12.3	9.4 (11.0)	43	37	9	18.8	11.2	35	32	7
Valley bottom (high elev.)												
2.7 x 2.7 m												
57*	1031 (190)	10.9	12.7	7.4 (7.9)	44	30	10	16.5	11.0	28	24	5
75	1166 (27)	19.4	15.1	13.4 (13.4)	224	200	35	25.9	15.8	89	83	13
3.7 x 3.7 m												
67*	641 (76)	15.7	13.2	9.4 (10.1)	61	52	12	20.2	11.9	43	39	8

[a] Largest 250 trees per hectare by diameter.
[b] Quadratic mean diameter.
[c] Average height of largest 100 trees per hectare by diameter.
[d] Age from seed.
[e] Values in brackets are number of naturals per hectare.
[f] The asterisk indicates plots with less than 80% survival of planted seedlings.
[g] Values in brackets are average heights without naturals.

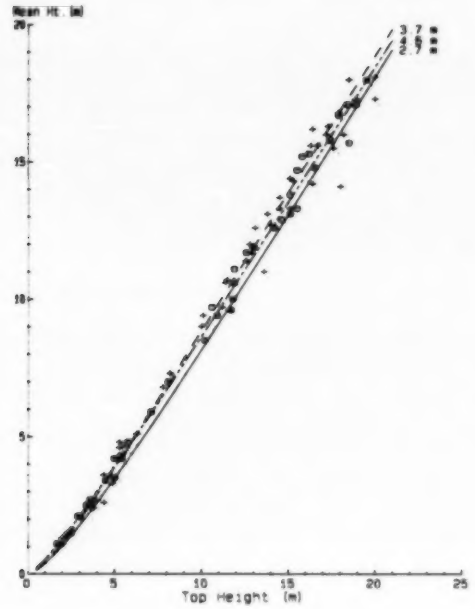
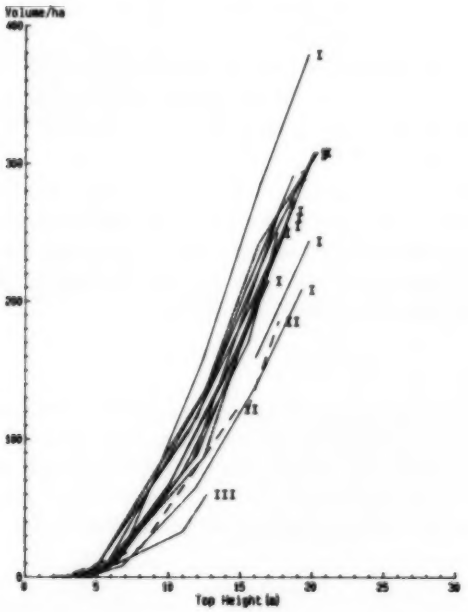


FIGURE 1. Douglas-fir average height versus top height by spacing.
——·— = 2.7-m spacing growth curve and data point
– – –+ = 3.7-m spacing growth curve and data point
—·—·—⊙ = 4.6-m spacing growth curve and data point



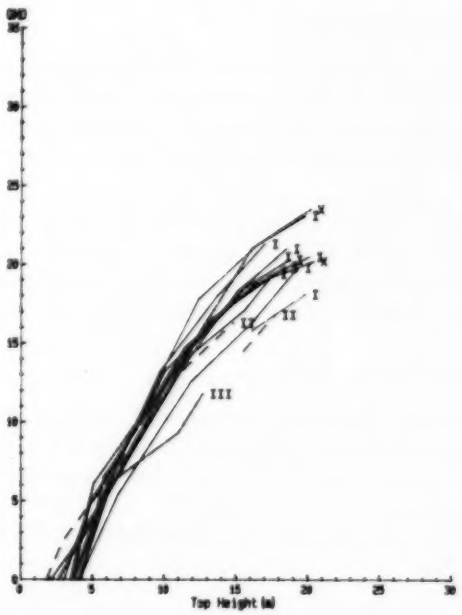


FIGURE 2. Effect of site index classes on the 2.7-m spacing volume/top height relationship.
——— = individual plot growth

Site class:
X = 42.5 + m at 50 years breast-height age
I = 37.5 - 42.4-m at 50 years breast-height age
II = 32.5 - 37.4-m at 50 years breast-height age
III = 27.5 - 32.4-m at 50 years breast-height age
Site index was based on Bruce's (1981) site curves.

Average diameter:

The entire-stand quadratic mean diameter growth curve corresponding to the 2.7-m spacing was significantly different from those of the 3.7- and 4.6-m spacings, which were similar. The three spacings defined a common curve until the relatively close 2.7- and 3.7-m spacings began to "peel off" at top heights 5 and 15 m, respectively (Figure 3). Similar results were obtained with quadratic and arithmetic mean diameters both for crop trees and for the entire stand. This implies that inter-tree competition starts at about 5 m top height in the 2.7-m spacing, and at about 15 m top height in the 3.7-m spacing. Consequently, stands should be precommercialy thinned before reaching these heights to avoid declines in diameter growth.

Basal area:

The basal-area-per-hectare growth curves for the entire stand in the three regimes decreased significantly from the 2.7- to 4.6-m spacings (Figure 4). Basal area per tree and crop-tree basal area per hectare were highest at the 4.6-m spacings. Basal area per hectare at any attained top height was higher at the 2.7-m spacing because the many small trees at this spacing easily overwhelmed the few larger trees at the other spacings. Beyond top height 15 m, basal-area-per-hectare growth rate was found to be declining at the 3.7-m spacing (Figure 4). This decline may be an artifact, or a real occurrence that is due to the relatively lower number of trees and declining tree diameter growth at this regime. Thus, initial spacing significantly affects basal area by lowering total yields per unit area, and increasing the basal area per tree at the widely spaced stands.

Total volume:

Results and conclusions similar to those found for basal area were obtained for the spacing effects on total volume (Figure 5). Total volume per hectare was lower and total volume per tree was higher at the widely spaced stands.

Merchantable volume:

Initial spacing impact on merchantable volume, defined as the total volume between a 30-cm high stump and a 10-cm diameter inside bark top, was similar to that for total volume. Merchantable volume per hectare was significantly lower at the 4.6-m spacing than at the other spacings (Figure 6); however, merchantable volume per tree was significantly higher at the 4.6-m spacings (Figure 7).

Wide spacing provided large trees which became merchantable at an earlier date than would normally happen. However, because the merchantable volumes were soon overwhelmed by the relatively numerous trees in closely spaced stands (trees which reached merchantable dimension later), the rankings were reversed. It is important to note that conclusions on initial spacing effects may change depending on how "merchantable volume" is defined in terms of the stump height and top diameter limits.

Diameter distributions:

Model 1 was fitted to the pooled diameter cumulative percentage frequency data from Port Renfrew and Franklin River, and the resulting curves were depicted graphically (Figure 8). These curves can be used to estimate the proportion of stems below a given diameter utilization limit at ages 24 to 25. For example, 85, 45, and 35% of the stems would be below the 22.5-cm diameter limit in the 2.7-, 3.7- and 4.6-m spacings, respectively, indicating that wider initial spacing provided more usable stems per hectare earlier than did close spacing.

WESTERN REDCEDAR

Growth curve comparisons indicated that differences are expected and reasonable but not yet statistically significant among the initial spacing regimes (Figures 9-13). However, salal competition and browsing might have masked any real differences in the stand values due to initial spacing. Stand values at ages 24 to 26 years are summarized in Table 8.

Sitka spruce

Sitka spruce weevil, or white pine weevil, (*Pissodes strobi* Peck.) had repeatedly attacked the Sitka spruce trees after age 8, thus affecting height growth and causing severe stem deformities such as forking, crookedness, and poor tops. This prevented use of the same method of analysis applied to Douglas-fir and western redcedar. Instead, the trees were separated into weevilled (damaged) and unweevilled categories, and the remeasurement data at ages 24 to 26 were summarized (Table 9). The damaged trees at a given spacing were generally taller and larger than the undamaged ones, suggesting that the weevil preferred large, vigorous trees. The extent of damage was not related to initial spacing.

Western hemlock

Poor establishment survival significantly modified nominal initial spacing in the western hemlock plots. Twenty-four of 34 plots in Port Renfrew and Franklin River had less than 80% survival of planted trees in 1967. (The Mooyah Bay western hemlock plots were not assessed for survival in 1967, and have since been abandoned.) As a result, analysis to detect spacing effects in western hemlock was not done, although measurement data at ages 24 and 25 from well-stocked plots consisting of planted trees and naturally regenerated, replacement trees were summarized (Table 10). Planted trees were up to 1.8 m (average 0.7 m) taller than the naturally regenerated replacements, indicating the 2-year age advantage of plantations over natural regeneration.

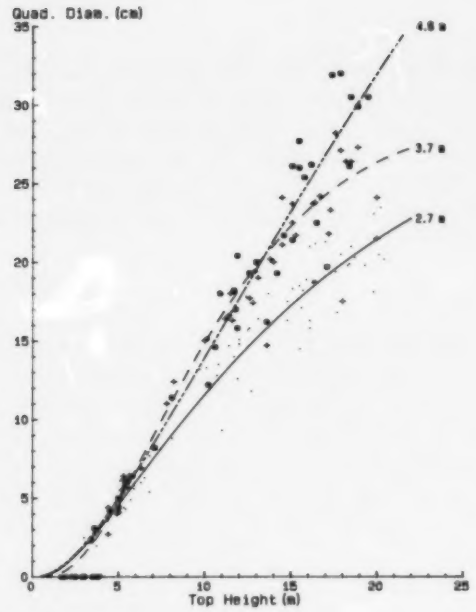


FIGURE 3. Douglas-fir quadratic mean diameter versus top height by spacing.
——·— = 2.7-m spacing growth curve and data point
— — —+ = 3.7-m spacing growth curve and data point
— — —⊖ = 4.6-m spacing growth curve and data point

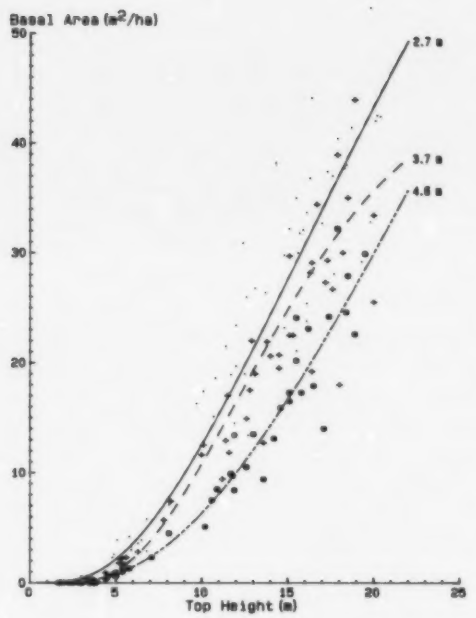


FIGURE 4. Douglas-fir basal area per hectare versus top height by spacing.
——·— = 2.7-m spacing growth curve and data point
— — —+ = 3.7-m spacing growth curve and data point
— — —⊖ = 4.6-m spacing growth curve and data point

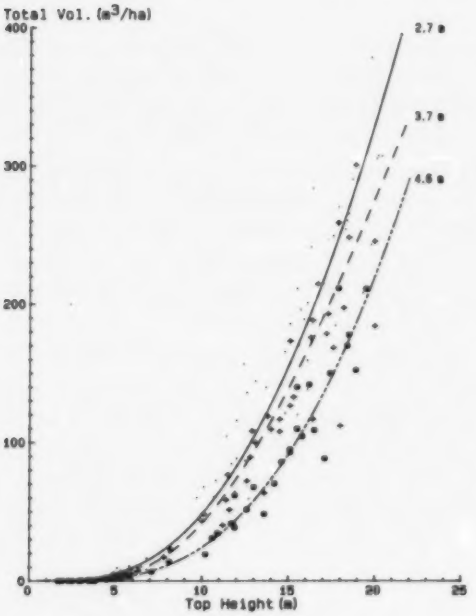


FIGURE 5. Douglas-fir total volume per hectare versus top height by spacing.
——·— = 2.7-m spacing growth curve and data point
— — —+ = 3.7-m spacing growth curve and data point
— — —⊖ = 4.6-m spacing growth curve and data point

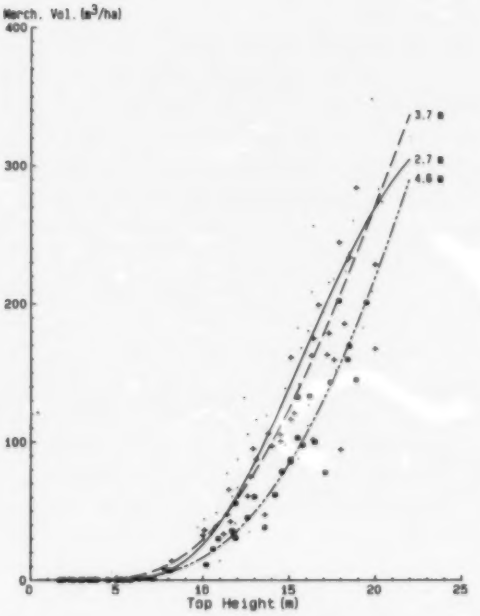


FIGURE 6. Douglas-fir merchantable volume per hectare versus top height by spacing.
——·— = 2.7-m spacing growth curve and data point
— — —+ = 3.7-m spacing growth curve and data point
— — —⊖ = 4.6-m spacing growth curve and data point

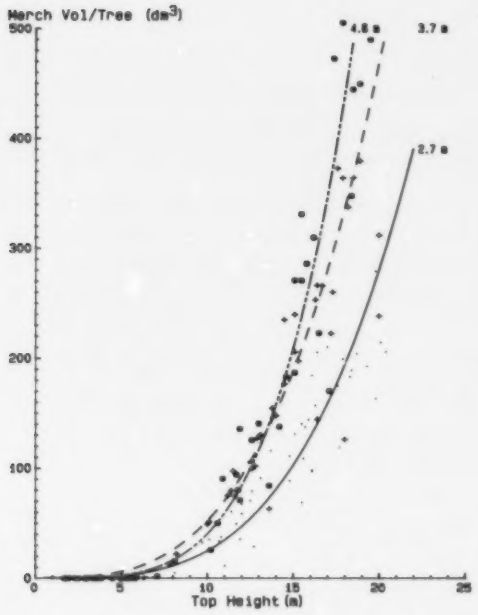


FIGURE 7. Douglas-fir merchantable volume per tree versus top height by spacing.
——· = 2.7-m spacing growth curve and data point
– – –+ = 3.7-m spacing growth curve and data point
——·—Θ = 4.6-m spacing growth curve and data point

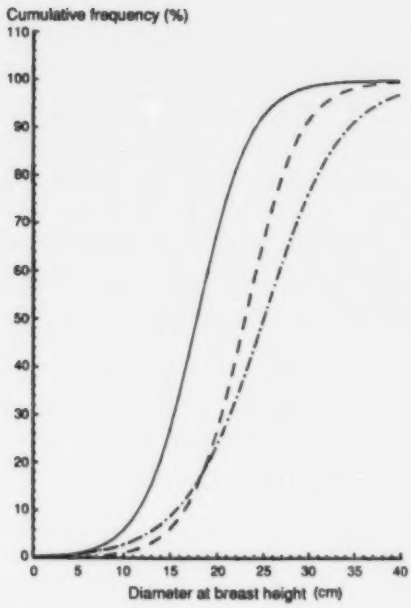


FIGURE 8. Douglas-fir diameter cumulative frequency distributions by spacing.
—— = 2.7-m spacing freq. % curve
– – – = 3.7-m spacing freq. % curve
—·—·— = 4.6-m spacing freq. % curve

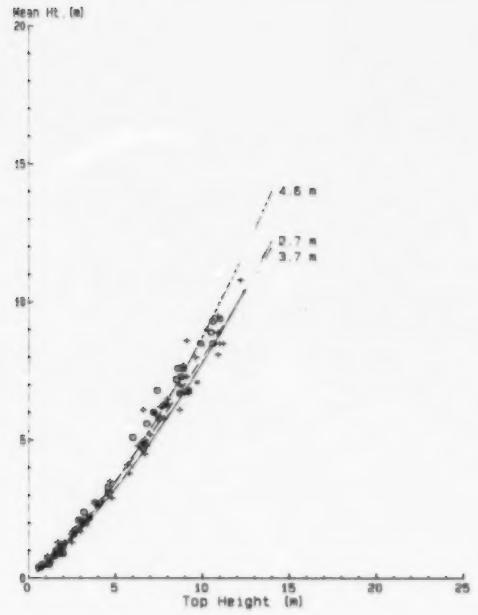


FIGURE 9. Western redcedar average height versus top height by spacing.
——· = 2.7-m spacing growth curve and data point
– – –+ = 3.7-m spacing growth curve and data point
——·—Θ = 4.6-m spacing growth curve and data point

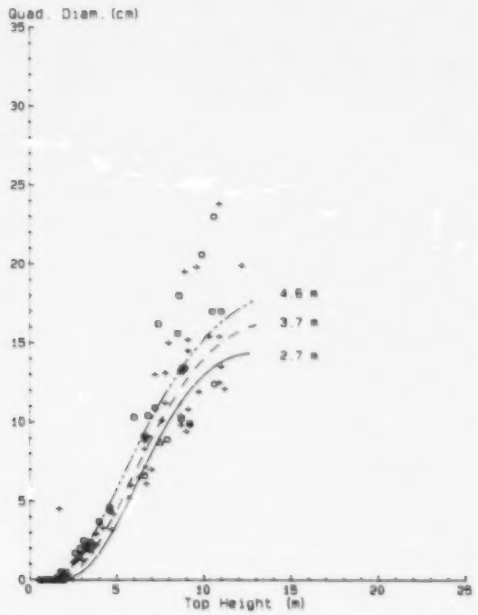


FIGURE 10. Western redcedar quadratic mean diameter versus top height by spacing.
——· = 2.7-m spacing growth curve and data point
– – –+ = 3.7-m spacing growth curve and data point
——·—Θ = 4.6-m spacing growth curve and data point

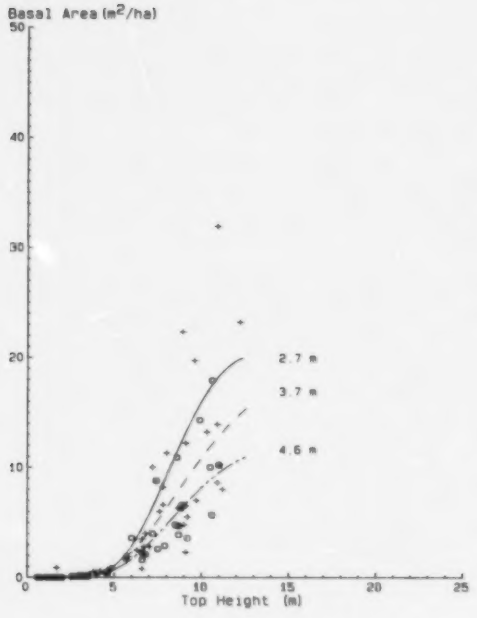


FIGURE 11. Western redcedar basal area per hectare versus top height by spacing.
——· = 2.7-m spacing growth curve and data point
– – –+ = 3.7-m spacing growth curve and data point
—··—O = 4.6-m spacing growth curve and data point

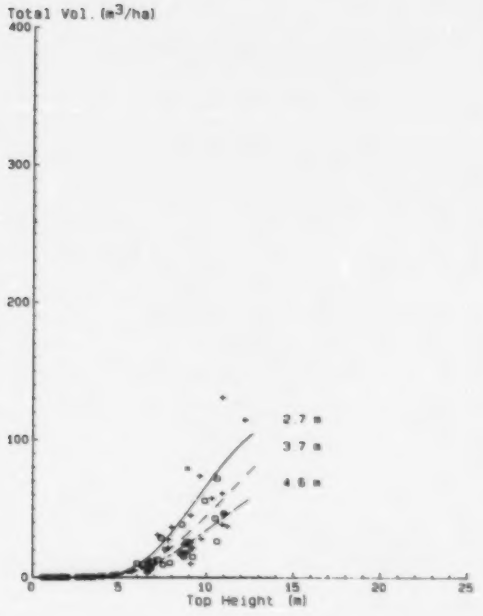


FIGURE 12. Western redcedar total volume per hectare versus top height by spacing.
——· = 2.7-m spacing growth curve and data point
– – –+ = 3.7-m spacing growth curve and data point
—··—O = 4.6-m spacing growth curve and data point

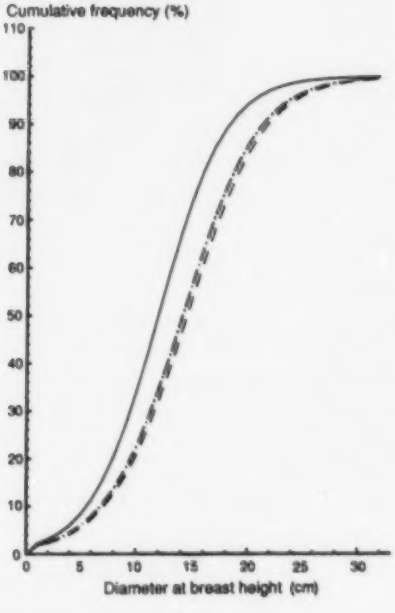


FIGURE 13. Western redcedar diameter cumulative frequency distributions by spacing.
——— = 2.7-m spacing freq. % curve
– – – = 3.7-m spacing freq. % curve
—·— = 4.6-m spacing freq. % curve

CONCLUSIONS

The results for the range of initial spacings, species, and conditions in this study indicated that:

- Initial spacing had no significant effect on seedling survival of Douglas-fir (86%), Sitka spruce (87%), western hemlock (56%), and western redcedar (91%).
- Douglas-fir growth and yield relationships to initial spacing were generally as expected: average height was virtually the same at all the spacings; wider spacings produced large trees which became merchantable sooner; and volume yield per hectare was lower at the wider spacings.
- Initial spacing effects in Sitka spruce, western hemlock, and western redcedar were delayed or confounded by salal competition, browsing (western redcedar), weevilling (Sitka spruce), and poor establishment survival (western hemlock).

Juvenile growth curves, which can help validate growth models and evaluate early plantation performance, have been developed for Douglas-fir and western redcedar. As well, the plots themselves provide unique opportunities for visually demonstrating the effects of the current range of operational stocking levels and tree species performance, and for investigating how salal, other lesser vegetation, and weevil damage affect tree and stand growth.

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